Quebec and the Phenomenon of Acid Precipitation: a Review

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QUÉBEC AND THE PHENOMENON OF ACID PRECIPITATION: A REVIEW

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FOREWORD

The present article is a translation and a reproduction of a text written originally in French and published in "Les carnets de zoologie", Vol. 42, No. 3 (1982).

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Introduction

The problem of acidic precipitation is not new; however, the concern that has been focussed on the phenomenon in Canada and the United States is fairly recent. Acid precipitation constitutes a serious problem: it is invisible, it is odourless, and it acts silently. Insidiously it becomes part of the natural physical, chemical, and biological mechanisms of our ecosystems, altering some of their important features. A certain knowledge of the effects of acid precipitation on Québec is beginning to take shape, and the aim of this article is to review the extent of this knowledge.

Québec is vulnerable in a number of ways to the effects of the long-range transport of air pollutants and of the resulting acidifying depositions. Geophysically, Québec is highly sensitive to acid deposition, as it is located on the Precambrian shield which, owing to the widespread lack of carbonates, has no buffering capacity for neutralizing acids from the precipitation that seeps into it.

Québec is also susceptible from the geographic standpoint. Lying in the path of major air currents that are "loaded" upwind with strong acidifying pollutants, it is strategically located for sustaining the worst effects of this atmospheric pollution.

The expanses of water that cover 10% of southern Québec are especially vulnerable from the biological standpoint. The flora and fauna of many of the affected areas are remarkably abundant; the vast forests and the rich aquatic life of the lakes are ample evidence of this.

The final aspect of Québec's particular vulnerability is economic. In the tourist sector, sport fishing accounts for annual sales of $250 million. It is thought that a somewhat lower yield may be linked to acid depositions. The richness of Québec's soil is a vital factor in its agricultural production and, in particular, in its large forest industry. Some facts seem to point toward the harmful effects of acid depositions on Québec's soil, whether agricultural or forest land. Since agriculture accounts for $2.2 billion in sales annually and the forestry industry has a market of $3.9 billion per year, $2.9 billion from exports, it is easily seen that even if the disruptive effect of acid deposition on these industries is only slight, the economic loss suffered by Québec may still be quite substantial. For example, adding an extra five years to the some fifty years needed for a forest to reach maturity would mean an average yearly loss of $390 million.

Causes and Mechanisms

The transport of air pollutants is a phenomenon that manifested itself for the first time when man discovered fire. It worsened with the coming of industrialization and the resultant explosive increase in the emission of contaminants into the atmosphere. Transport itself is therefore nothing new. What is relatively recent, however, is the "long-range" aspect of the phenomenon. Starting in the 1950s, in an attempt to mitigate the serious local effects of pollutants given off into the atmosphere, the height of smoke stacks was raised fairly systematically. A vertical increase of a few hundred metres extended the horizontal range of the emissions to some thousands of kilometres, and what was once a purely local problem ended up having an international context.

For reasons of geography and climate, Québec is a prime target for acidic deposition. The general circulation of the Earth's atmosphere is characterized by two semi-permanent anticyclones, one over the Atlantic, the other over the Pacific. The Atlantic anticyclone, normally in the latitude of Bermuda, favours a low-altitude flow of air that sweeps northward over most of the territory east of the Rocky Mountains. This southerly flow varies in strength depending on the interaction of the meteorological systems that move across the same landmass; in general, however, it is stronger in summer than in winter. A

major characteristic of the flow is that it transports atmospheric pollutants emitted in heavily industrialized, densely populated areas, such as Ontario and the American East and Midwest, toward Québec. As a further feature of this long-range transport, it should be pointed out that the phenomenon is restricted to a layer of the lower atmosphere. This layer is a thin stratum directly above the Earth's surface, its thickness varying typically from 400 metres in winter to 1600 metres in summer. Pollutants injected at the base of the layer generally remain there; occasionally, however, some of them are carried into the upper atmosphere by strong convection currents.

Acid rain is the commonly used term. Yet it would be more accurate to speak of "acid deposition", for the fallout can be either in liquid (rain), solid (snow), or particulate form (aerosols). Pollutants are given off into the atmosphere as gases, liquids, vapours, or particles. Their fallout from the atmosphere occurs through various mechanisms which may be divided into wet deposition processes (the formation, growth and washout of cloud droplets) and dry processes (sedimentation, accumulation, impact and absorption) (see Bridge and Fairchild, 1981).

Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are very widespread atmospheric pollutants; they have been identified as

the major precursors to acid deposition. Sulfur dioxide is soluble in water and can be extracted directly by washout Nitrogen oxides, on the other hand, are not soluble and direct extraction by washout is limited. Most SO_2 and NO_x is dispersed in the atmosphere by air currents and is transformed into various sulfate and nitrate particulates. When sulfates and nitrates are exposed to humidity, they change into sulfuric and nitric acid. These two types of acid account for 90% of the acidity found in rain and snow samples (Altshuller and McBean, 1980).

Although sulfates and nitrates have attracted special attention because of their importance in the chemical content of acid precipitation, they are in fact only examples of the various types of deposition linked to atmospheric transport. There are other acidifying compounds whose sources are similar to those of SO_2 and NO_x. Furthermore, there are some compounds contained in wet and dry depositions that are potentially harmful to human beings as well as to plants, animals and building materials. These compounds include ammonium ions, carbon, certain organic products and certain trace metals from industrial processes (Zn, Cu, Fe, Al, Pb, Cd, Vn, Hg, As and Ni).

Emissions and Chemical Transformation of Air Pollutants

The pollutants that are said to be precursors to acidification are mainly oxidized components of either sulfur (SO_x) or nitrogen (NO_x). Of these two types of pollutants, the first is thought to play the larger role. Nitrogen oxides also have secondary effects that favour the formation of ozone in the lower strata of the atmosphere; this gas can be very harmful if, for instance, it comes into contact with the leaves of trees or plants.

The magnitude and geographical distribution of sulfur dioxide (SO_2) emissions are shown in Figure 1 (Ontario Ministry of the Environment, 1980). The major emission concentrations in the Eastern United States and particularly in the Midwest are noticeable because of their intensity and their extent. In Canada, the SO_2 emissions associated with INCO's operations in Sudbury and Noranda Mines in Noranda, though heavy, are very localized. The United States emits 26.9 million tonnes of sulfur dioxide annually, Canada 4.8 million tonnes and Québec 1.1 million tonnes. Noranda Mines is responsible for more than 50% of the SO_2 emitted in Québec; 0.6 million tonnes per year. The American Midwest, because of its many thermal power stations, accounts for the major part of the SO_2 given off south of the border. Figure 2 shows the main NO_x emission areas for Eastern North America. The pollution created in large cities and densely

populated areas is easily discernible, for nitrogen oxides, which are produced with varying degrees of efficiency by all processes of combustion, are generated in large part by motor vehicles. Here again there is a substantial concentration in the American Midwest: the thermal power plants that emit SO_2 also give off NO_x, owing to their high temperatures; nonetheless, the magnitude of their NO_x emissions is lower than that of the transportation sector. The United States, Canada and Québec emit respectively 20.2, 2.0 and 0.3 million tonnes of NO_x per year; in Canada, 50% of this production is due to the transportation sector.

Sulfur and nitrogen compounds are transformed into acids through various mechanisms and at various rates. Very polluted air, like that found in the Ohio valley, contributes to rapid transformation rates near the source of the emissions; SO_2 gas is transformed into SO_4 particulate matter at rates in the order of 5 to 10% per hour. In cleaner air, like that found in central Ontario or in Québec, the rate of conversion is estimated to be around 0.5% per hour. Owing to its general remoteness from the principal sources of sulfur emissions, Québec is affected in particular by particulate SO_4, which as it comes into contact with a moist environment -- whether it be humidity, rain, snow or an expanse of water -- is transformed into sulfuric acid ($H_2 SO_4$), and nitrogen oxides (NO_x) into nitric acid (HNO_3) under the same circumstances. The transformation mechanisms

of nitrogen, its rates of transformation, and how these mechanisms interact with other atmospheric constituents are, however, less well known than those of sulfur. Yet the fact remains that in both cases there are far more questions than answers and that, furthermore, it will not always be possible to make the most of research results that pertain to environments different from Québec's.

Measurement of the degree to which precipitated snow or rain is polluted as a result of the emission, long-range transport and transformation of SO_2 and NO_x is obtained through chemical analysis of precipitation samples collected by the monitoring network set up for that purpose. The average acidity (pH) values recorded for precipitation in Eastern North America between April 1979 and March 1980 are shown in Figure 3. The particular way in which the pH values are distributed geographically is characteristic of the acid rain phenomenon in North America. An axis of maximum acidity (i.e. distribution of minimum pH values) stretches from the Midwestern states to the St. Lawrence valley. This pH distribution says a great deal about the origin and causes of acidic precipitation in Québec.

In short, then, it is fairly clear that Québec, situated in the path of major air currents that are loaded upwind by many large sources -- American ones in particular -- of sulfur and

nitrogen compounds, finds itself at the mercy of these unwanted exports and thus fated to struggle against the noxious effects they generate.

Data on the Effects of Acid Deposition in Québec

Québec has only fairly recently begun to show any serious interest in the phenomena of long-range transport of air pollutants that have an impact on the acidification of its territory. A few preliminary studies have been done that have shed a certain light on the problem. According to a study carried out jointly by the ministère de l'Environnement and the ministère du Loisir, de la Chasse et de la Pêche (MLCP) (see Charette and Lagacé, 1981) using data collected between 1970 and 1978 on sixty-three lakes, there seems to be an inverse correlation between the acidity level of the lakes and the yield of brook trout fished from them. Richard (1982) reviewed the study in the light of new, additional data in greater quantity and variety. They suggest that the lower yield of the acidified lakes that was noted by Charette and Lagacé (1981) between 1970 and 1978 would more likely be attributable to the lakes' being underfished rather than to the effects of the acid lake water. A substantial increase in the number of man-hours spent fishing these same acidified lakes between 1978 and 1981 produced fish yields that reach levels as high as those found in lakes that are not or are only slightly acidified. Richard

(1982) is careful to point out, nonetheless, that these new results do not mean that brook trout populations are not being affected by the gradual acidification of lake water, but rather that the data available do not enable us to make this deduction and that only a more extensive analysis of the physiological state of the fish in question and of their population structure would furnish adequate information. Conductivity and pH data gathered from 1333 lakes located south of the 51st parallel were analysed by Grimard (1981) on behalf of the ministère de l'Environnement du Québec. Results show that 52%, 28% and 10% of these lakes have pH values of less than 6.0, 5.5 and 5.0 respectively. Furthermore, the geographical distribution of pH values in the lakes north of the St. Lawrence, i.e. in the Precambrian shield, is similar to the distribution found in the lake systems of south-central Ontario and southern Norway, both of which are regarded as being affected considerably by acidic precipitation. Figure 4 (Grimard, 1981) shows that Québec lakes in hydrographic areas from which water flows into the Ottawa or St. Lawrence rivers or the Gulf of St. Lawrence (curves Q2 and Q3) have acidity level distributions equivalent to those of lakes that are recognized as acidified: south-central Ontario (curve i1), Mont-la-Cloche, Ontario (curve i3) and southern Norway (curve i2). This comparative analysis induces us to believe that acidic deposition has caused an increase in the acidity level of lakes throughout Québec's Precambrian shield.

The geographical distribution of pH values for the 1333 lakes studied is shown in Figure 5. It can be seen that a vast area that takes in the headwaters of the Saint-Maurice, Batiscan, Sainte-Anne, Jacques-Cartier, Montmorency, Chicoutimi, Mětabetchouane, and Nottaway river basins presents average pH values of less than 5.5 (the average having been calculated for grid squares of one degree longitude by one degree latitude). It can also be seen that the lakes of the Gaspé Peninsula have much higher pH values, the bedrock of the region containing a significant amount of calcareous matter.

If the alkalinity level of its lakes is considered, Québec appears to be very susceptible to acid deposition. A recent multiparameter study of 256 lakes done by Bobée, Grimard, Lachance and Tessier (1982) for the ministère de l'Environnement du Québec has shown that 143 or 56% of them are classified as being extremely sensitive because of low alkalinity and that 43 or 17% of them are classified as completely acidified, i.e. with zero alkalinity. It can be seen in Figure 6 (Bobée et al., 1982) that the relatively high count of sulfate ions in the lakes is evidence that these acidic depositions originate in the atmosphere. Furthermore, the horizontal gradient of the concentration of this ion is a clear indication of the direction of the flow, besides pointing toward its source. Later in this paper we shall touch on the Québec government's studies and research projects that are in progress.

Some provinces, Ontario in particular, and some countries, such as the United States and Norway, have been doing work in the field of acid precipitation for several years now. Some of their research results can be used here by assuming they are valid for Québec, though they may have to be verified at a later date. Both direct and indirect effects on forests have been discovered: airborne acidity damages plant life by making it more susceptible to pathogenic elements and insects and by making it more sensitive to other pollutants; second, acidity promotes increased activity of certain toxic metals, such as aluminum, which can attack the roots of trees and limit their growth. Along the same lines, the leaching of various metals (Al, Hg, Cd, Cu, Pb, etc.) that occurs when acid-stressed water seeps into the soil contributes to increasing the toxicity of rivers and lakes and to making the toxic effects felt throughout the food chain: from benthos to plankton to fish.

Very little evidence is available concerning the harmful effects of acid deposition on human health. Nevertheless, there are enough signs to justify our believing that a real problem exists. Respiratory difficulties and illnesses may be directly aggravated by the inhalation of aerosols that are precursors to dry deposition. It is difficult to demonstrate the cause-and-effect relationship, however, with regard to the other pollutants present (Canada-United States Report, 1981). Second, there is a danger of contamination through ingestion of fish, whose tissues

contain high concentrations of toxic substances. Third, the pipes and equipment used for water storage and distribution systems may corrode, and there is a risk of certain metals (Pb, Cd, Cu, Zn) contaminating drinking water reservoirs (see Fuhs and Olsen, 1979; Bridge and Fairchild, 1981).

Acidic deposition, oxidizing agents, gases and particulate matter are acknowledged to be contributing factors in the early discolouration and deterioration or corrosion of certain building materials. The materials that are affected include, in particular, metal building supplies, masonry constituents containing carbonates (limestone, marble), plastics, elastomers, paints and organic coatings.

At this point it would be wise to mention a policy paper that, without being scientific, nevertheless had a great impact both inside and outside Québec. The paper in question is a brief submitted to the United States Environmental Protection Agency in September of 1981 (Ministère de l'Environnement, 1981) stressing Québec's strong opposition to the planned easing of SO_2 emission restrictions in the United States. Though written in a political context, this brief furnished an opportunity to assess the phenomenon of acid precipitation in Québec. Much of the information contained in the present article was taken from that brief.

Sulfurous Acid Deposition and Relative Responsibility

From results published in the 1981 Canada-United States Report, dealing with the first of three phases of the project, it is possible to come to a preliminary estimate of the amount of sulfur deposited in two zones of Québec. The results from five numerical models simulating long-range transport and dry deposition of sulfur compounds were used. It should be emphasized that these preliminary results are only indicative; moreover, they are valid only for two well-determined zones: Le Parc des Laurentides and the border area separating the Cantons de l'Est from Vermont. The overall results of these calculations are presented in condensed form in Figure 7. Of the depositions that fall on Le Parc des Laurentides 15% are emitted by sources in Québec, 25% come from sources in Ontario, 38% from the Midwest, and 22% from the Eastern part of the United States. Results are similar for the Québec-Vermont border zone: 19% of the depositions come from Québec, 3% from the Maritimes, 12% from Ontario, 30% from the Midwest states, and 36% from the eastern American states. In the first zone, American sources are thus responsible for 60% of the depositions, while in the second, they are responsible for 66%. One additional point that should be noted is that dry depositions, to judge by the results of the models, would be in the same order of magnitude as wet depositions.

Hypothetical Effects of a Change in American Emission Standards

As already stated, Québec has sent the American Environmental Protection Agency (EPA) a brief (Ministère de l'Environnement, 1981) expressing its strong opposition to the planned easing of the present standards contained in the Clean Air Act. Several Midwest states (Ohio, Michigan, Illinois, Indiana, Tennessee and West Virginia) that wish to take advantage of this easing of the law have asked the EPA for permission to raise their SO_2 emission levels. Using numerical data for increased emissions, we have estimated the annual fallout that would strike the same two Québec receptor zones. The new share of relative responsibility is illustrated in Figure 8. In Le Parc des Laurentides, sulfur deposition would rise from 23 to 32 kilograms of sulfur per hectare per year (kg S ha^{-1} yr^{-1}), an increase of 38%. In the other zone, there would be a 34% increase (from 26 to 35 kg S ha^{-1} yr^{-1}). Comparing Figures 7 and 8, it can be seen that the Midwestern states, whose emissions would go up under the hypothesis in question, would see their relative responsibility rise from 35% to 55% for Le Parc des Laurentides and from 30% to 48% in the second receptor zone.

It is logical, therefore, and even imperative for Québec to do everything in its power not only to counter an increase in its pollutant burden but also to reduce the present input of its incident acidic pollution. There are three kinds of

concrete action Québec is taking, or thinking of taking, to attain this objective; they will be the subject of the remainder of this article.

Studies and Activities in Progress

Various surveys and studies are now in progress. During the summer of 1981, the Service de la météorologie of the ministère de l'Environnement set up a network for taking weekly samplings of acidic deposition. This network consists of 46 stations, most of which are located in the southern half of Québec. In association with this network, an original system for the chemical analysis of precipitation has been developed by the department's Direction des laboratoires. Based on measurements of conductivity in liquid and using resin as an ion exchanger, this system produces more accurate analyses than do conventional methods, as well as turning them out much more rapidly.

An intensive campaign to measure the acidity of Québec's lakes has been undertaken by the Service de la qualité des eaux of the ministère de l'Environnement in conjunction with the federal Fisheries and Oceans department and Environment Canada. This campaign involves measuring many parameters relating to acidification for some 500 lakes spread out across the southern half of Québec.

A statistical-type numerical model capable of simulating the long and medium-range transport of air pollutant is being developed by the INRS-EAU. It will be used in determining how much of Québec's total acid deposition is attributable to the operations of Noranda Mines.

The brook trout is a species of fish that plays a key role in the success of sport fishing in Québec. It is thus important for us to find out how the species reacts to high levels of acidity. For this purpose, the ministère de l'Environnement is funding a researcher from the biology department of Université Laval. He will attempt to determine the impact of acidic precipitation on the generation and growth rate of brook trout fry; his results are expected to be available at the end of the summer of 1982.

Two socio-economic studies have also been undertaken. Already well on its way to completion, the first study involves, in its initial phase, devising a methodology for determining the socio-economic impact of lake acidification on sport fishing in Québec. The second study involves determining the socio-economic viability of imposing sulfur-dioxide emission restrictions on Noranda Mines' copper refinery. The results of this research should be available sometime in the fall of 1982.

Strategies for Reducing SO_2 Emissions in Québec

In 1976, Québec was responsible for emitting 1 105 000 tonnes of sulfur dioxide into the atmosphere. These emissions come from various sectors of industrial activity, and responsibility may be broken down into the following percentages: 54% from basic copper smelting, 30% from the use of fuels for industrial, commercial, and residential purposes, 7% from oil refining, 3% from sulfite pulp production, 2% from aluminum smelting, and so on.

From 1976 to 1979, sulfur dioxide emissions in Québec decreased slightly to 1 029 000 tonnes per year. The gouvernement du Québec is now committed to implementing an abatement strategy whose overall target is an annual sulfur dioxide production of only 747 000 tonnes by 1985, i.e. a reduction of 27%. The possibility is even being considered, according to certain hypotheses, of our being able to reduce our emissions to 575 000 tonnes per year by about 1987. Our abatement program is based on two major elements. The first involves carrying out a substantial reduction, of about 40%, between now and 1985 of the SO_2 emissions from Noranda Mines, with whom the ministère de l'Environnement is negotiating at present; this reduction is linked to the construction of a sulfuric acid plant (setting up a pilot plant that would use sulfur dioxide and asbestos waste for producing magnesium sulfate fertilizer has also been proposed). Concurrently

with its efforts at Noranda Mines, Québec will make sure that the second largest copper producer in the province, Mines Gaspé, will optimize operation of its smelter and its sulfuric acid plant so as to recuperate at least 65% of the sulfur introduced into the production process. The second element that will work in favour of reducing SO_2 emissions is Québec's energy policy. The energy conservation program and the increasing use of natural gas are expected to reduce oil consumption substantially. Furthermore, the fact that Québec is turning more and more toward hydro electricity will increase electricity's share of the total energy market by 25 to 40% between 1979 and 1990.

By reorienting its energy policy and by severely reducing SO_2 emissions from its own industries, Québec is clearly displaying its firm intention to combat those causes of acidification that come under its jurisdiction. For our neighbours to the south, these efforts will thus attest to Québec's strong opposition to a new rise in American air-pollutant emissions that would contribute to increasing the already high acidification of our territory.

Research Projects in Québec

The extent of the acid precipitation problem in Québec has given rise to a fairly impressive mobilization of resources in certain government departments. A common front made up of the ministère de l'Environnement (MENVIQ), the ministère de l'Énergie et des Ressources (MER), the ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPA), the ministère de l'Industrie, du Commerce et du Tourisme (MICT) and the ministère du Loisir, de la Chasse et de la Pêche (MLCP) has been formed, and a plan for an inter-departmental program of study and research has been drawn up. This plan, which provides for a series of activities spread out over five years, has been submitted to government authorities for examination and approval.

Each of the departments concerned has identified its needs and formulated its requests. At the MENVIQ, a considerable number of projects have been proposed: studying the quality and quantity of atmospheric depositions, determining the physical and chemical changes associated with the acidification of lakes and rivers, identifying the impact on aquatic biota (plankton and fish), determining the maximum admissible input of acidic deposition on Québec's territory, monitoring the evolution of the problem of acid deposition, making localized attempts to restore certain acidified lakes, identifying the socio-economic effects of the

acidic precipitation phenomenon, and finally, establishing an information program for annual assessments of the evolution of the acid precipitation issue.

The MER has identified the sectors of activity in which it is particularly interested, including the assessment of the impact of acidic precipitation on the regeneration, growth and health of forests.

The MAPA has planned studies for determining the tolerance thresholds of certain species of plants when exposed to high levels of acidity, for identifying the characteristic symptoms of damage to plant life, and for establishing product quality criteria. Furthermore, the MAPA would like to ascertain the present condition of Québec agricultural land and the rate at which it is deteriorating: cartography of the physical and chemical characteristics of the soil and establishment of a sensitivity scale for soil exposed to rapid acidification would be adequate to meet these objectives. In the animal production sector, the MAPA is interested in detecting any possible influence acidic surface water may have on the health and breeding quality of both fish and farm animals.

Summary and Conclusions

In this article we have attempted to present a fairly comprehensive, and inevitably somewhat condensed picture of the phenomenon of acid precipitation and its effects on Québec. It has been noted that pollution sources give off sulfur and nitrogen compounds into the atmosphere; transported over long distances, these compounds reach most of Québec's territory and are major factors in its gradual acidification. Certain effects that have been studied, in particular in the case of the acidification of lakes, attest to the extent of the problem and tend to show that the research carried out to date has only succeeded in skimming the surface of the question.

Using numerical models, estimates have been made of the annual rates-- both actual and hypothetical-- of sulfur fallout on two regions of Québec. In the hypothetical case, estimates were based on American SO_2 emissions being raised to the levels requested by the Midwestern states. In both cases, it has been quantitatively determined that our neighbours to the south are responsible for the major part of the acidic fallout that affects Québec.

We have detailed the past and present action taken on this issue: a network for monitoring acidic precipitation,

development of an original method of chemical analysis, a campaign to measure the quality of lake water, a strategy for reducing Québec's sulfur dioxide production by 27% by 1985, and submission of a brief to the Environmental Protection Agency stressing Québec's strong opposition to the planned easing of SO_2 emission standards in the United States. We also touched on what the gouvernement du Québec plans to do about this question in the future. We mentioned that a plan for an interdepartmental research program had been drawn up. It is designed to shed light on the effects of acidification in the environmental, agricultural, forestry, socio-economic, and fisheries sectors. Conceived as a five-year project, the program will supply additional data and the knowledge required for managing Québec's territory in a coherent manner and for implementing certain solutions. It will also provide the official responsible for the acid precipitation question with solid scientific arguments supporting the government's claims against present sources of pollution, whether they be inside or outside Québec.

Acid Precipitation: Figures

Figure 1: Eastern North America -- Major SO_2 Emitting Areas (Ontario Ministry of the Environment, 1980)

Figure 2: Eastern North America - Major NO_x Emitting Areas (Ontario Ministry of the Environment, 1980)

Figure 3: Average pH values for precipitation from April 1979 to March 1980

Figure 4: Cumulative distribution of pH values recorded inside and outside Québec (Grimard, 1981)

Figure 5: Geographical distribution of average pH values, calculated for grid squares of one degree longitude by one degree latitude (Grimard, 1981)

Figure 6: Classification by sulfate values of the lakes studied -- summer 1981 (Bobée et al., 1982)

Figure 7: Origin of and relative responsibility for the fallout of sulfur compounds on two target areas affecting Québec -- PRESENT STATE

Figure 8: Origin of and relative responsibility for the fallout of sulfur compounds on two target areas affecting Québec --EXPECTED STATE if American emission restrictions are eased.

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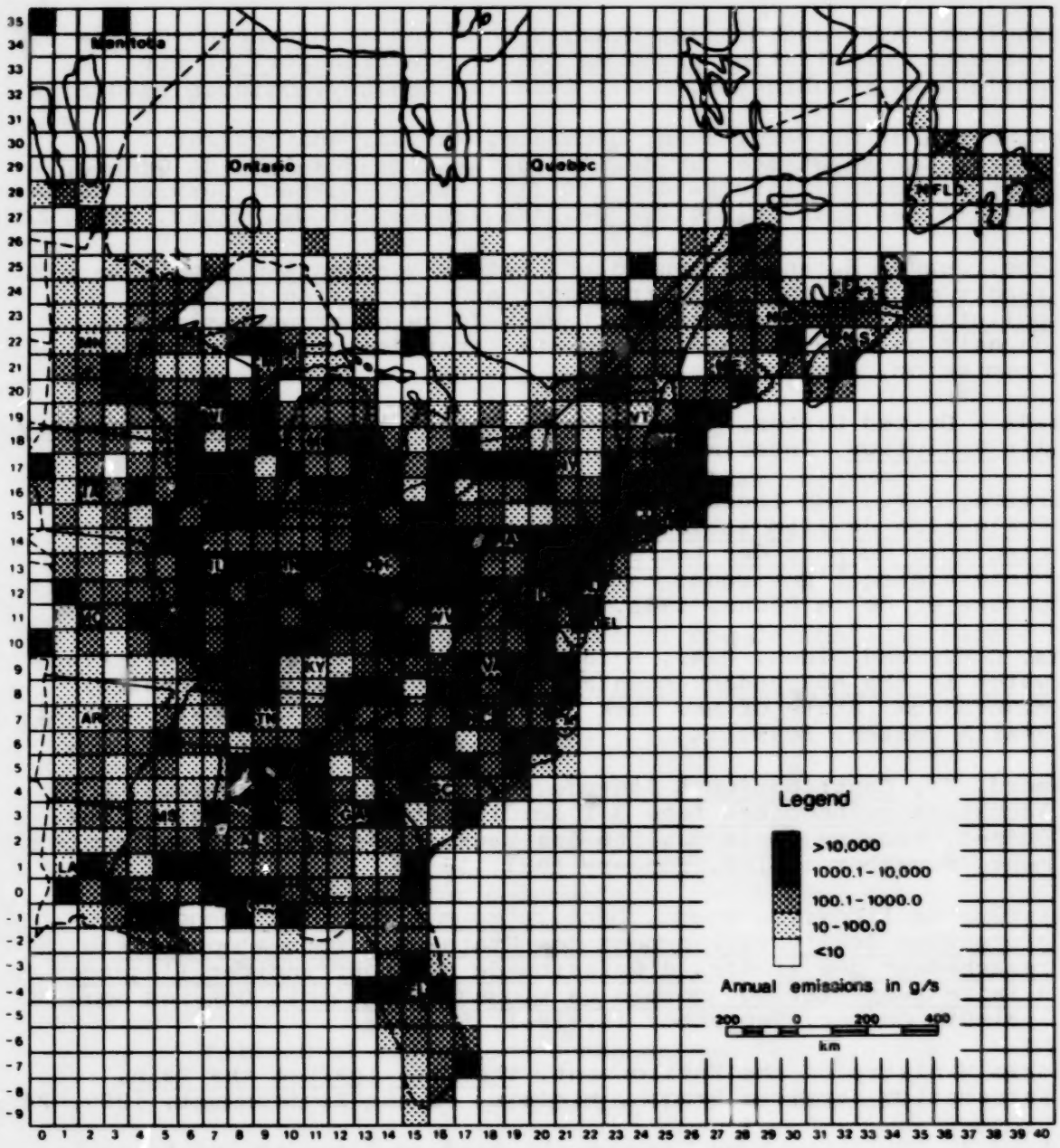

FIGURE 1

EASTERN NORTH AMERICA MAJOR SO_2 EMITTING AREAS

(ONTARIO MINISTRY OF THE ENVIRONMENT, 1980)

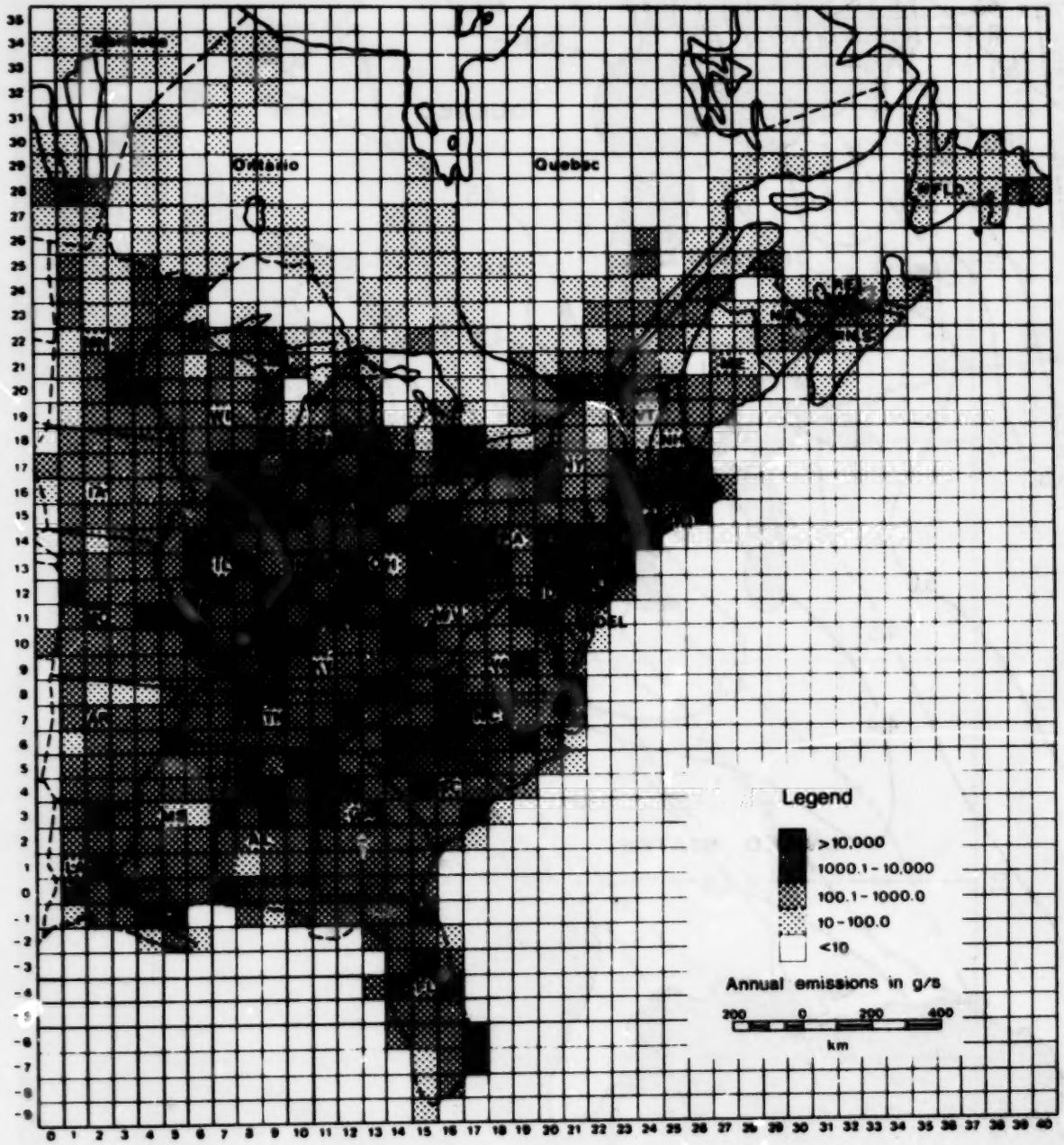

FIGURE 2

EASTERN NORTH AMERICA MAJOR NO_x EMITTING AREAS

(ONTARIO MINISTRY OF THE ENVIRONMENT, 1980)

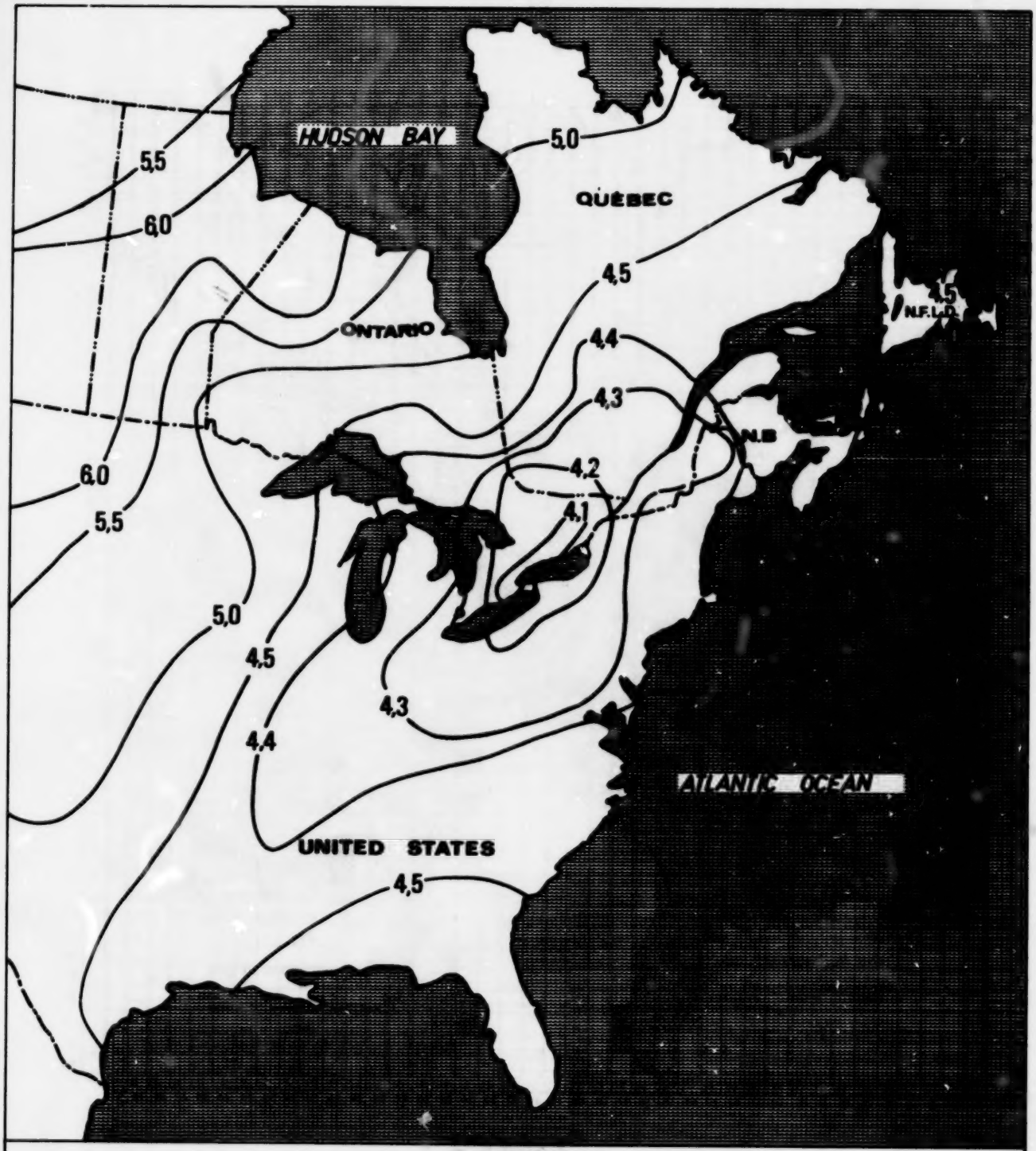

FIGURE 3

AVERAGE pH VALUES FOR PRECIPITATION FROM APRIL 1979 TO MARCH 1980

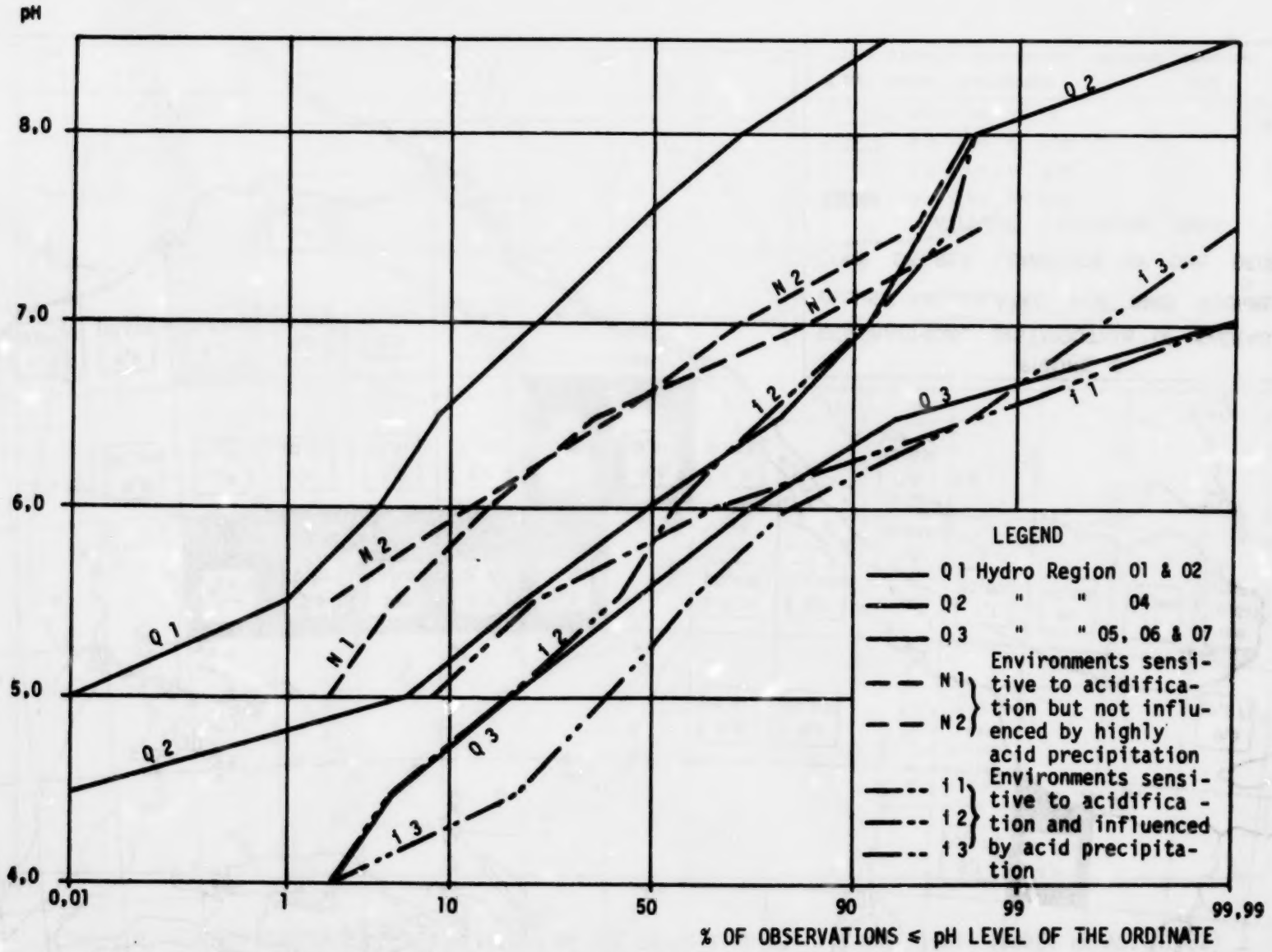

Figure 4 CUMULATIVE DISTRIBUTION OF pH VALUES RECORDED INSIDE AND OUTSIDE QUÉBEC (GRIMARD, 1981)

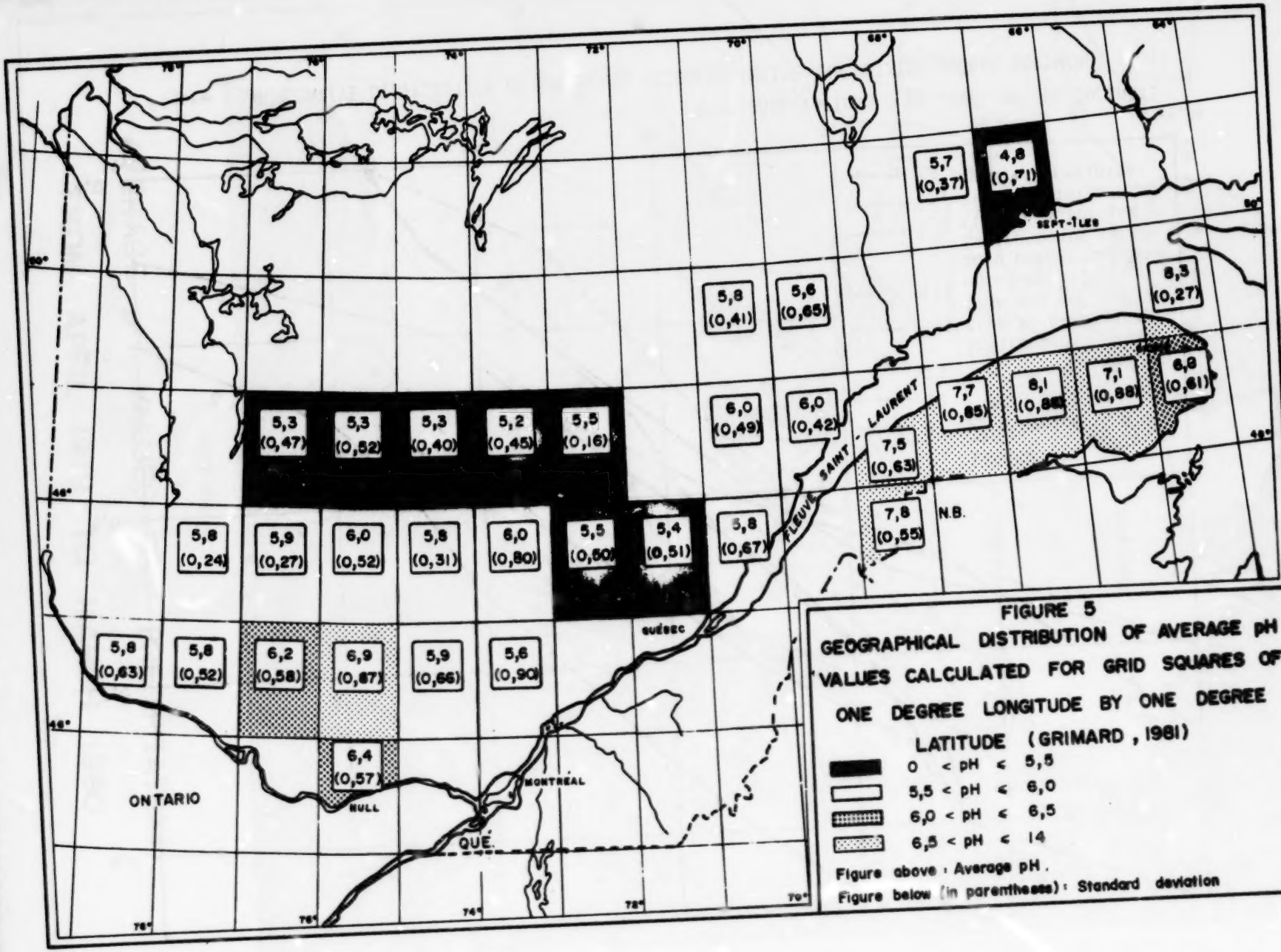

FIGURE 5

GEOGRAPHICAL DISTRIBUTION OF AVERAGE pH VALUES CALCULATED FOR GRID SQUARES OF ONE DEGREE LONGITUDE BY ONE DEGREE LATITUDE (GRIMARD, 1981)

- 0 < pH ≤ 5,5
- 5,5 < pH ≤ 6,0
- 6,0 < pH ≤ 6,5
- 6,5 < pH ≤ 14

Figure above : Average pH.
Figure below (in parentheses) : Standard deviation

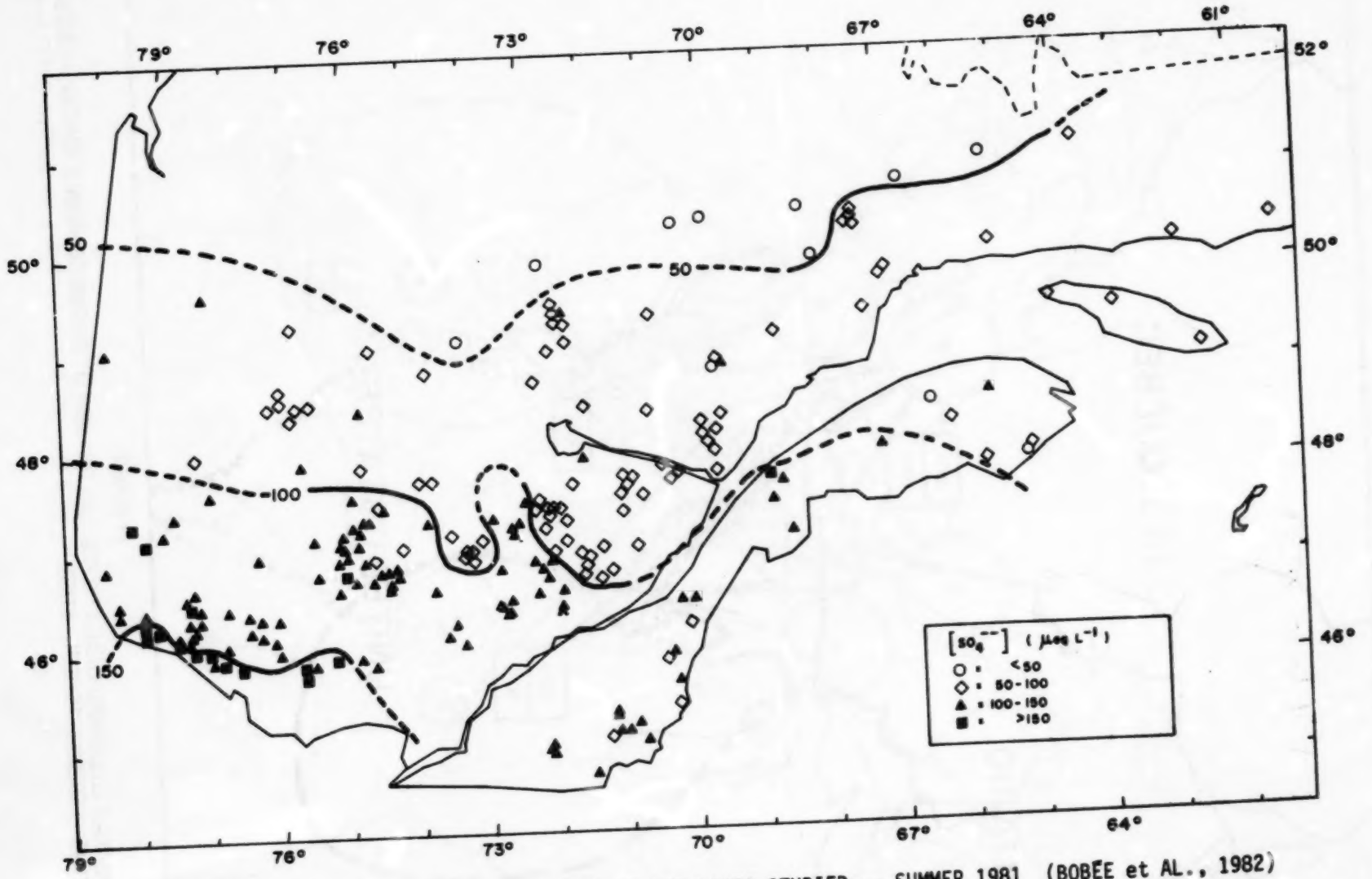

Figure 6 CLASSIFICATION BY SULFATE VALUES OF THE LAKES STUDIED -- SUMMER 1981 (BOBÉE et AL., 1982)

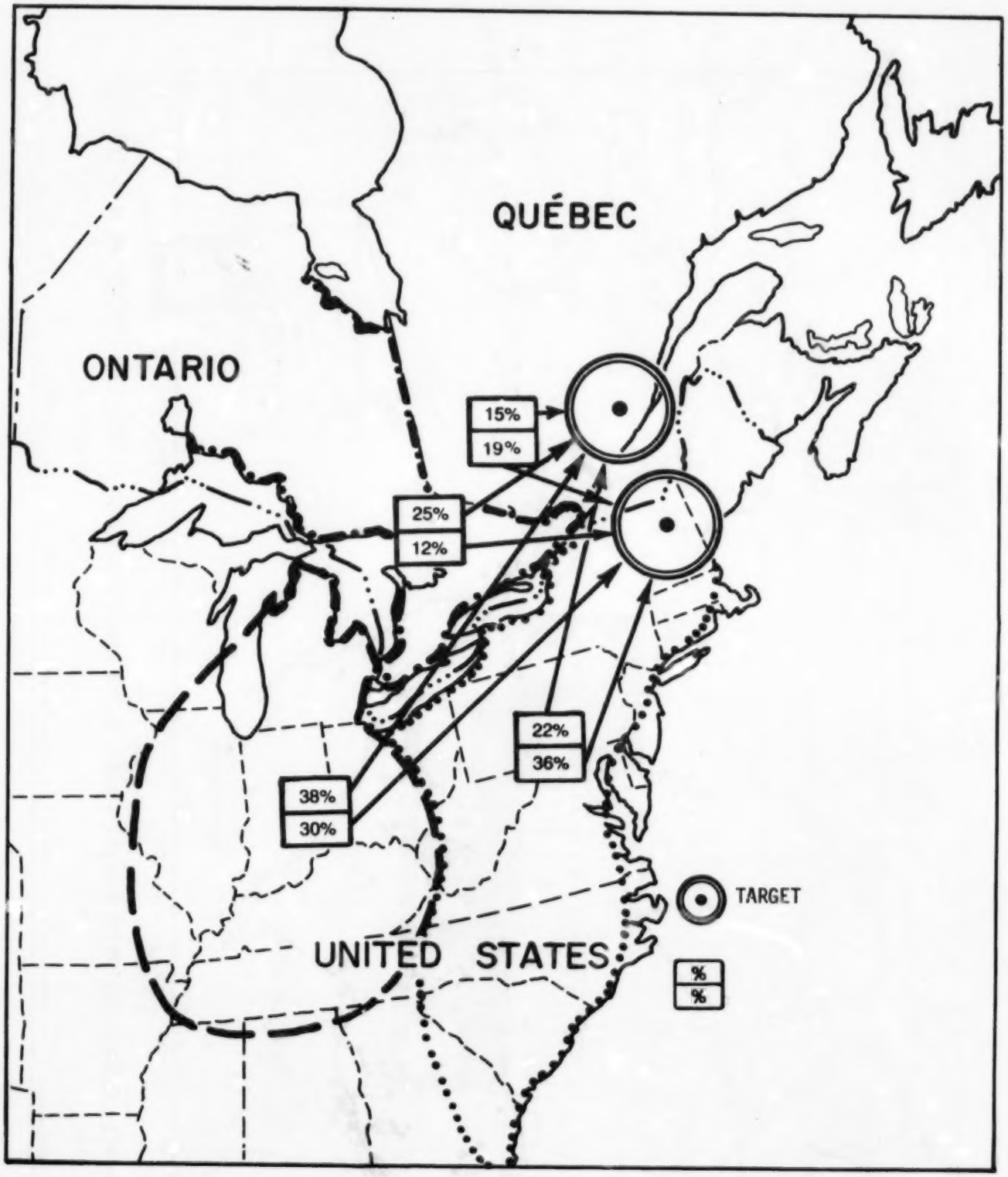

Figure 7

ORIGIN OF AND RELATIVE RESPONSABILITY FOR THE FALLOUT OF SULFUR COMPOUNDS ON TWO TARGET AREAS AFFECTING QUÉBEC -- PRESENT STATE

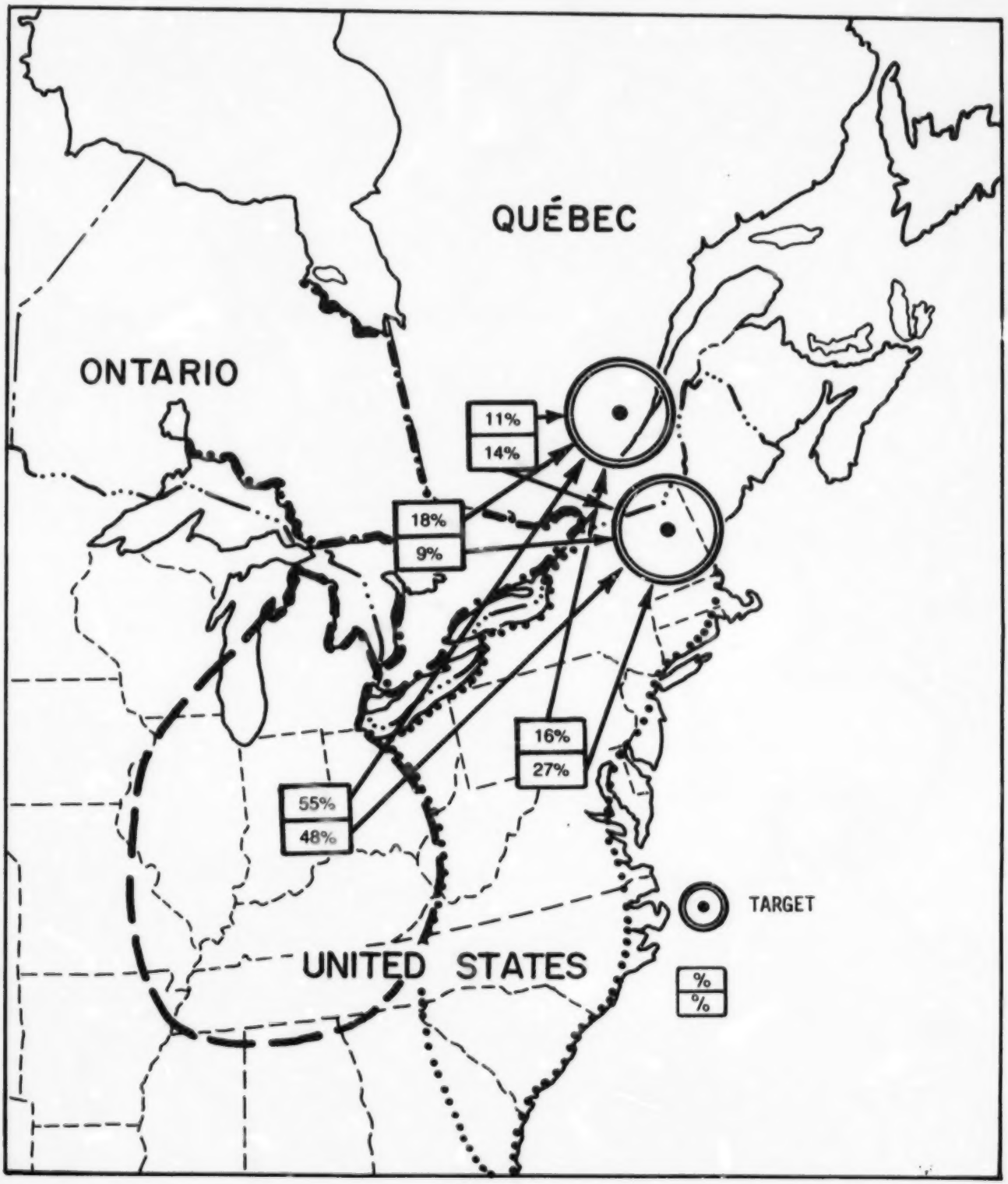

Figure 8

ORIGIN AND RELATIVE RESPONSABILITY FOR THE FALLOUT OF SULFUR COMPOUNDS ON TWO TARGET AREAS AFFECTING QUÉBEC -- EXPECTED STATE IF AMERICAN EMISSION RESTRICTIONS ARE EASED